

# Measurement and Numerical Simulation of Wind Environment for One Residential District

Can Li  
Doctoral Candidate  
Associate Professor

Hunan University of Technology,  
Zhuzhou, P.R.China  
lc19992@126.com

Nianping Li  
Professor

College of Civil Engineering, Hunan University  
Changsha, P.R.China

**Abstract:** A residential quarter in the west of Changsha has a nearby main transport corridor to the east, and Tianma Hill is to the west. The circumference of this residential quarter is open to the outside; therefore, the wind environment is special. In this study the wind environment of this area is measured and the influence factor is analyzed. Based on these testing data, some of which are regarded as the boundary conditions, this study employs the commercial software FLUENT to calculate the wind field of this district. The results are compared with the testing data. Under average wind velocity conditions of predominant wind in summer and winter, the wind environment is predicted. The numerical calculation results agree well with the testing data. FLUENT can predict the wind field effectively for varied boundary conditions.

**Key word:** residential district, wind environment, test, numerical simulation

## 1. INTRODUCTION

In recent years, people pay more attention to the environment condition of residential quarter. Thermal environment factors influence the residents' thermal comfort, at the same time, it affects the energy consumption of the building. Therefore, it is becoming important. The micro-thermal environment of the residential quarter usually includes temperature and humidity of air, wind velocity, solar radiation etc. These factors depend upon corresponding parameters of the city weather, and are influenced by the surrounding environment and the arrangement of buildings on the district,

architecture pattern and the function of construction etc. To programming and building, the action mechanism of the above factors affects the thermal environment of the district and needs to be understood.

A test of the thermal environment of one residential quarter in Changsha is carried out, then the velocity field of the district is simulated and analyzed. This study mainly concerns the wind environment and discusses the wind environment condition and simulation method, aiming to provide a reference method of building arrangement and pattern which will be beneficial to airflow organizing when planning or designing buildings.

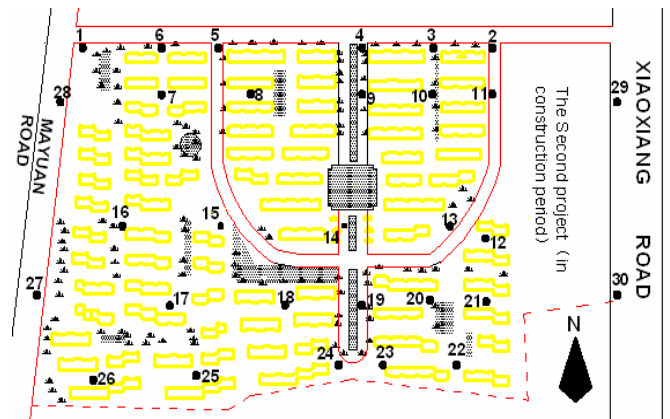
## 2. TESTING

### 2.1 Survey

The test chooses a new district, which is located on the west bank of Xiangjiang, in the east is Xiaoxiang road, the transportation trunk, and in the west is Tianma hill. It connects the transportation trunk in the south and north, and is open to the outside on each side. Figure 1 shows the distribution of the residential quarter. In the area, there are 80 buildings with concrete structure constructed. Most of them have 5 layers and some of them have 6 layers.

Changsha (east longitude 113°, north latitude 28°12') is in the subtropics, the four seasons are distinct, it is cold in winter and hot in summer. The temperature difference of one day is small. The coldest month is January, in which the average air temperature is 4.6℃, and the hottest month is July, in which the average air temperature is 29.5℃. Average wind

velocity in winter is 2.8m/s, and prevailing wind directions are northwest and partial to the north. In summer the predominant wind which average velocity is 2.6m/s is in the south. Choose Jan. 13 in 2006 as winter testing day, on that day it is cloudy and light frost, and the air temperature is 5□ to 9□. The average relative humidity is 70 %. The predominant wind is in the northwest and wind force is the 2ed grade. The item of observation include wind velocity and direction of each measure spot, air humidity, surface temperature of building and different underground face etc. Otherwise, the thermal comfort condition questionnaire to the residents has been carried on. The purpose of test is to observe and describe the thermal environment of the district which has been constructed already, at the same time, it is provides the boundary condition of calculation and check the result for numerical simulation.



• Fig.1 Plot plan of quarter and test pot position

## 2.2 Testing Procedure of Wind Environment

### 2.2.1 Testing Item of Wind Environment and Instrument

Testing spot position, testing parameter and instrument are shown as table 1, and spot place is shown as Fig 1.

**Tab.1 wind environment testing parameter, instrument and data processing**

Testing item	Testing spot position	Instrument type、number	Method of data collection	Data processing
Direction and velocity of Wind	1(2 testing pot in 1.5m and 6.5m height respectively)	Cup anemometer ,two (ZDR-1F, EL-1)	<ul style="list-style-type: none"> <li>• Collect average air velocity per minuet</li> <li>• record continuously by anemography</li> </ul>	<ul style="list-style-type: none"> <li>• Describe wind velocity profile in vertical direction</li> <li>• conduct exponent equation</li> </ul>
Air velocity	2~26	Electronic anemometer ,four (EY3-2A) digital anemometer, one (TESTO405V1)	Record a data per 30 Minuet by hand operating	<ul style="list-style-type: none"> <li>• Plot outdoor air velocity daily variation chart</li> <li>• compare calculation results with measurement data for each test spot</li> </ul>

Among these data, the velocity and direction of inflow wind is most special (testing spot 1), and that is important boundary condition of calculation. It is established at windward of predominant wind to gain exponent function of coming flow wind velocity (gradient wind). This literary introduces index rate method which is put forward by A.G.Davenport [2] to describe the exponent function of wind velocity which is vertical to the ground.

$$v = v_0 \left( \frac{z}{z_0} \right)^\alpha \quad (1)$$

where  $z$  and  $z_0$  are, respectively, random highness and reference highness,  $v$  and  $v_0$  are respectively average wind velocity at random height and at reference height,  $\alpha$  is relevant index of the area where building located. Based on (1), it is indicated that, as long as measure a set of wind velocity of coming flow in different height can

get  $\alpha$  value. Therefore arrange instruments at 1.5m and 6.5m at the position of spot 1, test the velocity and direction of wind of two point synchronously.

Other test spots of wind velocity and temperature and humidity are established at the height which is 1.5m from the ground. That is, intensively variety of temperature and humidity below 1.5m from the ground. Moreover the region that contributing the thermal comfortable feeling of people is within 1.5m to 2m from the ground.

### • 2.2.2 Error analysis

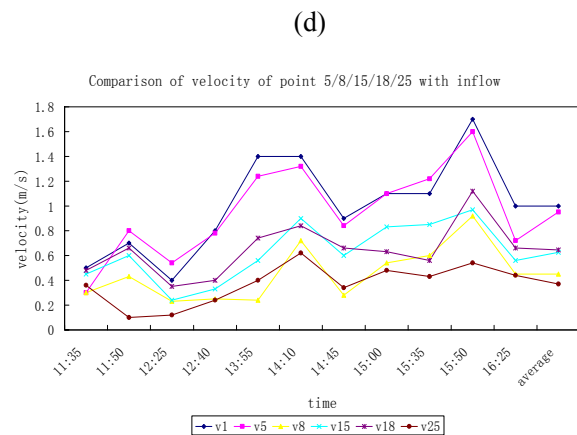
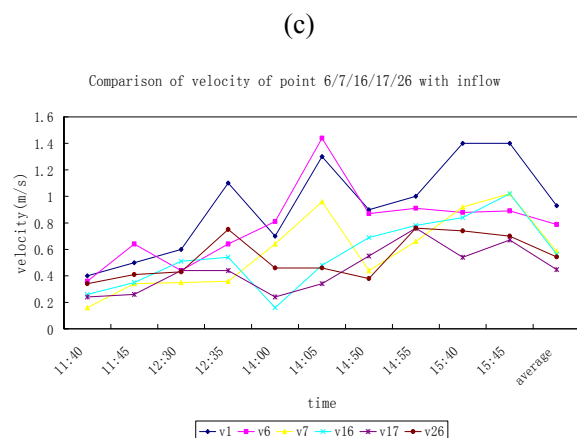
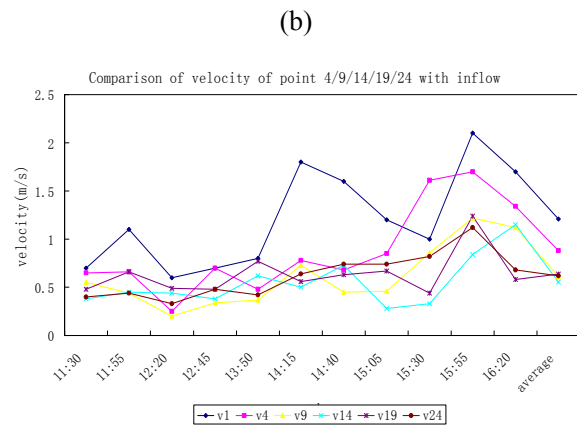
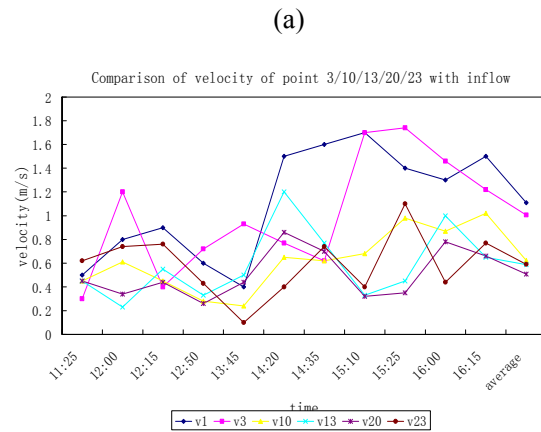
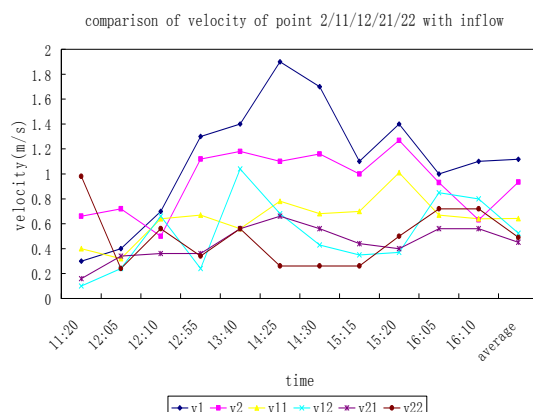
The system error is aroused by the influence of moving automobile and the activity of the pedestrian, observation of different instrument, the difference of each instrument and the difference between every time tool for observation. The difference of observation spots because of imprecise spots and the difference of instrument reading are the source of the personal error.

Based on the method of eliminating the data which is obviously affected by the activity of people and correcting each observation instrument and time tool, system error is amended. However, the personal error should be avoided by the testing personnel.

### 2.3. Analysis of the data of wind environment

Just list the result of observational data of airflow field. Prevailing wind direction in the testing day is partial north northwest.

The data of each spots at 1.5m and the variable value each 5minutes of the velocity of coming flow are shown such as Fig.2.



(e)

• Fig.2 compare of the measurement data of testing

### spot velocity and inflow

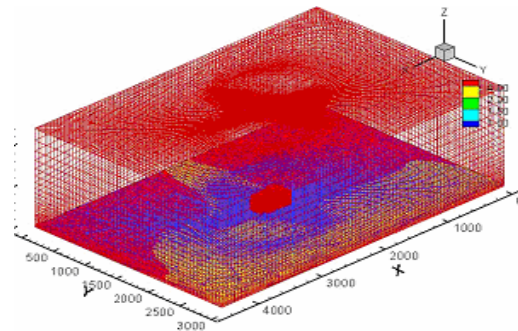
From the testing results, the average value of the velocity and direction of coming flow in each 1 minute changes more. The change range of other spots is smaller than which of coming flow. Among the testing spots, the spots with bigger average value of observation are 2,3,4,5,6. Secondly, the spots, of which average value is bigger than 60% spots of coming flow, are 7,15,18 etc. Spot 15 is nearby outdoor bazaar in the district. There is appropriate breeze environment in this situation, which not only be propitious to the diffusion of airflow but also will not make people unwell because of the bigger wind. The spots with average value which is much less than 1/2 average value of coming flow, locates in the middle region. These spots are blocked by building in the direction of dominant wind. It can not be neglected that the spots such as 2,3,4,5,6 face traffic trunk of this residential quarter. The influence of the 'automobile wind' is correspondingly bigger. The wind velocity is usually higher than coming flow. However, the average value and swing of the velocity of some spots is much less, it is likely to form detention region in the area as spot 25 shown in Fig.2 (e). The average value of all the spots is not higher than which of coming flow. It indicates that there is not prominent canyon wind phenomenon or obtuse effect. On the other hand, the dead angle region of flow with infinitesimal flow can not be discovered. It shows that there is not foul region in the area in winter because the open to outside of all direction of the area and the adequate space between building. Based on the arrangement of building, there is no condition which blocks flow completely because of regular disposing of buildings. However, because the height of each building is nearly equal, there is no condition of tower wind due to big difference between adjacent buildings.

## 3 NUMERICAL SIMULATION

### 3.1 Geometrical Model and the Scheme of mesh

The tool of numerical simulation is calculation software FLUENT. Considering inconspicuous influence to the whole wind field because of complicated and partial shape of single building, the

form of the building is simplified in term of geometrical model which is created according the main size of actual building. In calculation field, select length size of dominant direction (from south to north) which is about 10 times of building, 4438m. The height is 120m which is 8 times of building. It's seen as Fig.3.



• Fig.3 Mesh scheme

The calculation area is divided into two regions when divide mesh, a small hexahedron zone encircling buildings and the part outside. Hexahedron structure mesh is adopted. Inside of hexahedron zone micromesh is adopted, which space between mesh near building surface is 0.5m. Size function is defined to reduce the number of mesh. Furthermore, use the bigger structure mesh of which the biggest space is 10m. The total number of mesh is about 1,990,000. Practice proves that the convergence of this kind of mesh is very good.

### 3.2 Mathematical Model and Govern Equation

#### 2.2.1 Assumption

(1) The flow is low speed and uncompressing, and with steady turbulence all the time. It accord with Bossinesq hypothesis.

(2) Take no account of the sun radiation and any hot sources, and suppose airflow with constant temperature;

The weather is cloudy when test, the change of temperature of whole day is less. The underground surface with concrete of the testing district is simplification. There is not big lawn nor water region. It is comparatively accord with the condition of constant temperature.

### 3.2.2 Controlling equation and solution

#### Continuity equation

$$\frac{\partial u_j}{\partial x_j} = 0 \quad (2)$$

#### Momentum equation

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho} \frac{\partial p}{\partial x_i} + \frac{\mu}{\rho} \frac{\partial^2 u_i}{\partial x_j \partial x_j} - \frac{\partial}{\partial x_j} \left( \overline{u_i' u_j'} \right) + g_i \quad (3)$$

where

$$-\overline{u_i' u_j'} = \frac{1}{\rho} \mu_t \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) - \frac{2}{3} k \delta_{ij}.$$

Standard  $k-\varepsilon$  equation:

Equation of  $k$

$$\frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_i} (\rho k u_i) = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k - \rho \varepsilon \quad (4)$$

Equation of  $\varepsilon$

$$\frac{\partial}{\partial t} (\rho \varepsilon) + \frac{\partial}{\partial x_i} (\rho \varepsilon u_i) = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + C_{1\varepsilon} \frac{\varepsilon}{k} G_k - C_{2\varepsilon} \frac{\varepsilon^2}{k} \quad (5)$$

where

$$\mu_t = C_\mu \rho k^2 / \varepsilon.$$

In  $k-\varepsilon$  model,  $C_\mu$ 、 $C_1$ 、 $C_2$ 、 $\sigma_k$ 、 $\sigma_\varepsilon$  are, respectively, 0.09, 1.44, 1.92, 1.0, 1.3.

Adopt standard  $k-\varepsilon$  equation. In the course of discretization, the power law scheme and the 2<sup>nd</sup>-order central difference scheme is implemented for the convection and diffusion terms. The coupling between pressure and velocity is solved by SIMPLE algorithm. When resolve momentum equation and  $k-\varepsilon$  equation, the 1<sup>st</sup>-order central difference scheme is adopt to get convergent result, then 2<sup>nd</sup>-order central difference scheme is adopt to calculate in order to increase calculation precision.

### 3.3 Boundary Condition

Select the face which towards coming flow in calculation region to be inlet, and adopt boundary condition of velocity inlet. Write power function of velocity contour tested and simulated into computer program. According to the result of Fuyun ZHAO<sup>[3]</sup> at testing and the same area, select 0.3 as power

index and experience value<sup>[4-5]</sup> as overfall kinetic energy of inlet. The surface which is parallel with inlet is outlet, and the side face is assumed as symmetrical boundary. Top and ground are all assumed as no slip face. Considering the boundary of ground, adopt empirical data to dispose turbulence kinetic energy nearby ground and its dissipation ratio. Use pressure condition of outlet (assume the surface pressure of outlet to be zero) and boundary condition of outflow to calculate, then it is found that although the convergent course is different, result is nearly equal.

### 3.4 Results and Analysis

For compare with the testing results conveniently, select average velocity of real test as a condition to calculate. When  $Z = 1.5\text{m}$ ,  $V = 1\text{m/s}$ . According to equation (1), calculate  $V_0 =$

1.767m/s, and assume wind direction to be northwest (dominant direction in testing day), and then acquire velocity contour at 1.5m in the area such as Fig 5. The stream line plot of calculation is shown as Fig 6. As illustrated in table 2, we compare the calculation value of velocity( $V_c$ ) in each spot with average value of which measured data( $V_m$ ) on January 13, and calculate correlation

coefficient of them (CC) . Considering dominant wind direction in winter and summer in the area and corresponding average velocity, adopt, respectively,  $Z_0=10m, V_0=2.8m/s$ , and northern wind (simulate winter);  $Z_0=10m, V_0=2.6m/s$ , and southern wind (simulate summer) to be boundary condition. Otherwise, two cases are calculated.

**Tab.2 comparison of calculation value with testing value on January 13 and correlation coefficient**

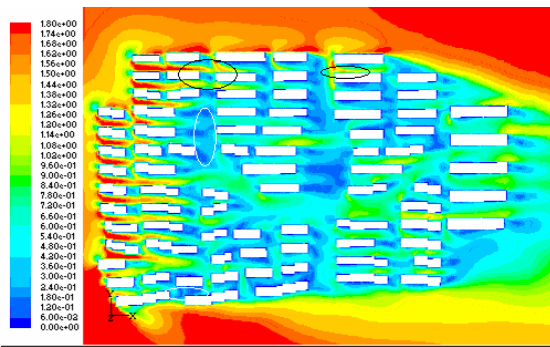
Spot	2	3	4	5	6	7	8	9	10	11	12	13	14
$V_c$	1.51	1.67	1.44	1.83	1.67	1.01	0.60	1.05	1.16	0.66	0.54	0.62	0.59
$V_m$	0.93	1.00	0.88	0.95	0.78	0.58	0.45	0.61	0.62	0.64	0.52	0.58	0.55
	4	5	2	1	8	5	1	3	3	3	4	7	5
Spot	15	16	17	18	19	20	21	22	23	24	25	26	CC
$V_c$	0.67	0.83	0.63	0.65	0.58	0.61	0.59	0.55	0.66	0.54	0.38	0.66	
$V_m$	0.62	0.56	0.44	0.64	0.63	0.50	0.45	0.49	0.59	0.61	0.37	0.54	0.85
	6	3	8	5	6	9	1	1	1	9		3	

Because actual velocity and direction of inflow change in a moment, it is not worth to compare calculating value and instantaneous value directly. However, comparing average value in testing time and calculating value can indicate the corresponding relation of tow trend. It's found that the linear correlative coefficient of them is 0.85, and it indicates that there is more correlative between the two aspects. Among the calculating results, the spots with little bigger velocity such as 2~6,9,10 are all agreement with result of observation. The velocity value of spot 7 and spot 16 is higher in the district, however, observation value is medium velocity. The calculation value of low velocity spot is good agreement against the testing results, where velocity value of spot 25 is the lowest. The other such as 11, 15, 18, 19, 20 are equal with testing value. According to the calculation results, velocity of each spot (include velocity heft of each direction in x/y/z), pressure and kinetic energy of turbulent flow. As is shown in chart 5, it is indicated obviously that laneway effect of some area (signed with black ellipse in Fig.5) and lower value of flow velocity no matter the dominant direction in winter and summer are both in negative pressure region. It is remarkable that these areas easily turn into block where airflow restore. Vortex situation of block and direction of airflow can be observed from streamline plot more convenience.

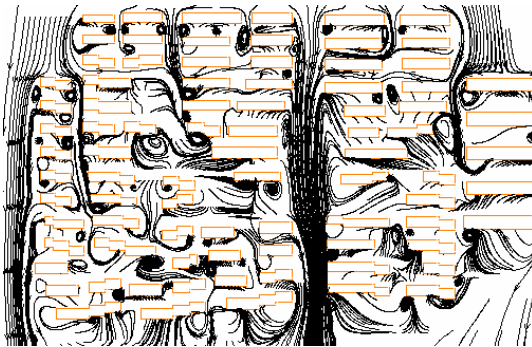
The velocity contour of wind speed at 1.5m height, when the flow direction are respectively south and north in summer and winter, is shown as Fig.7 and Fig.8.

#### 4. CONCLUSION

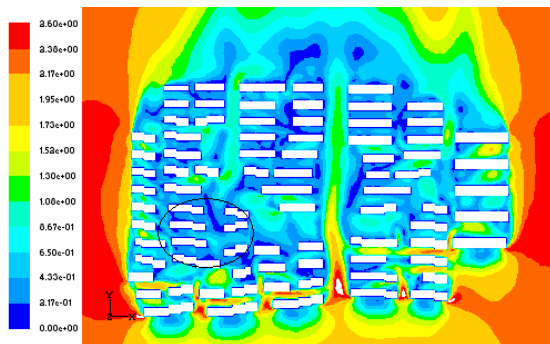
This paper has measured the wind environment of one residential quarter in winter, tested airflow field of multilayer building cluster quarter under typical weather condition, and made numerical calculation with some testing data as the boundary conditions. It's found that the comparisons between the simulation results and measured data are generally reasonable and acceptable with testing results. It is indicated that the method of numerical calculation is right, and boundary condition is reasonable. The paper has simulated the wind environment of the district with normal average velocity in winter and summer. According to calculation, we obtain flow situation of airflow, pressure distribution of wind, block eddy flow in the quarter, the situation forming laneway wind, the region where airflow easily restores etc.. At the same time, it can be used to forecast wind environment of the district under different weather condition. The method of simulation and calculation in the paper offers reference for planning and design, offers calculation results of airflow pattern of different arrangement and style of buildings.



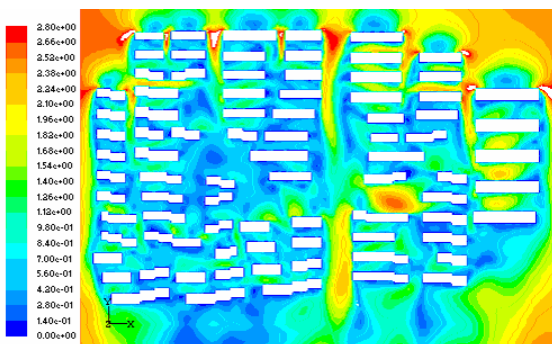
**Fig.5 Contour of velocity in 1.5m height**



**Fig.6 Stream line in 1.5m height in simulated test conditions**



**Fig.7 Contour of velocity in 1.5m height**



**Fig.8 Contour of velocity in 1.5m height 2.6m/s  
South wind as 2.8m/s as north wind**

## ACKNOWLEDGMENTS

The financial provided by A Project Supported by Scientific Research Fund of Hunan Provincial Education Department (No05D057) is grateful acknowledged.

## REFERENCES

- [1] Guoqiang Zhang, Shuizhou Ke, Jiangguo Peng. Design of high-rise building devise[M]. Hunan Science & Technology Press. Changsha Hunan. 1999. (In Chinese)
- [2] A.G.Davenport. The relationship of wind structure to wind loading. Proc of the symposium on wind effect on building and structures[J], London, 1965, (1):54-102
- [3] Fuyun Zhao. Numerical Simulation of Thermal Environment in Urban Residential District[D]. Hunan University , 2003 (In Chinese)
- [4] Yongsheng Zhou, Stathophouls T. Application of two-layer methods for the evaluation of wind effects on a cubic building [J]. ASHRAE Trans. 1996,102 (1): 754-764
- [5] Murakami S, Mochida A, Ooka R, et al. Numerical prediction of flow around a building with various turbulence models: comprison of K-ε KVM, ASM, DSM, AND LES with wind tunnel tests [J]. ASHRAE Trans. 1996,102 (1): 741-753